Results of NATO Task Group-23:
Battlefield Environmental Knowledge Based Rules for EO and MMW System Design and Assessment

Alan Wetmore — awetmore@arl.army.mil
U.S. Army Research Laboratory — 2800 Powder Mill Road — Adelphi, MD 20783
Voice: (301) 394-2499 — Fax: (301) 394-4797

BACIMO2003 9–11 September 2000 Monterey, CA USA

Abstract

In August 1999, an exploratory Meeting (SET-ET02) was held, and concluded there was a need for collaboration to co-operatively develop a framework to produce a product that would facilitate the design, optimization, and assessment of future sensors in both the natural and battlefield environment operating under a wide range of weather scenarios. NATO SET-041/TG23 was formed in the spring of 2000 with member nations Canada, germany, Netherlands, United Kingdom (chair) and the United States. The approach adopted was is based on first principles modeling of irradiance, illumination, and path losses derived from the state of the atmosphere as defined by weather observations. The methodology depends on the use of an extended period of meteorological records.

Overview

The changing role and nature of military operations conducted within NATO opens up an increasing range of potential operational scenarios. The traditional operational areas must now be replaced with previously unconsidered environmental characteristics; such as 'hot and dry', 'hot and humid', and 'extreme cold'. As an alternative to expensive field measurements programs, we have developed a methodology for extracting the critical weather information from sets of routine hourly observations that enable the analyst to exercise system simulation models with accurate weather conditions representing adverse and extreme weather impacts to systems. These results have been applied to four geographic areas, six target types, and ground and sky backgrounds. In addition a methodology for estimating smoke effects in these scenarios is shown. Nine meteorological parameters were determined to be of immediate importance to the study of sensor performance: Visibility, Relative Humidity, Temperature, Pressure, Dew Point Temperature, Low Cloud Amount, Wind Speed, Wind Direction, and Precipitation.

We identified key new scenarios where the assessment of EO sensor performance will be required but is currently not available. Generic scenarios were jointly selected by the Task Group and include both a traditional NATO and a newer operational area. Specific locations exhibiting these conditions were identified and weather data produced. A statistical characterization of the data was undertaken which provided baseline information

Introduction

The purpose of the methodology developed is to replace unconditional/uncorrelated average or adverse weather values with a correlated set of weather parameters selected from an archive of hourly surface observation reports. This insures that the values used in the system performance models represent actual weather (average, adverse, or extreme) conditions that actually occur in a particular region. In addition the general sensitivity of different target and sensor types to environmental variables is illustrated. The methodology is applied to a record period of one or more years of (preferably) hourly observations, thus capturing the seasonal and diurnal trends of the weather conditions as well as having sufficient observations to develop distributions of the measured variables.

The scenarios studied were: Northern Europe (Norway); Middle-East (Jeddah); Tropical Littoral (Key West and Singapore); Mountainous (White Sands, New Mexico). These locations were chosen as representative of areas of interest, as well as having good sources of data available.

Targets

In the optical and near-IR domain, the appearance of targets is primarily defined by the paint schemes used, whereas the actual weather conditions are of secondary importance. In the mid-IR (3–5 μm), the signature is a mixture of reflected solar and emitted irradiation, where the latter results from hot spots or heated surfaces. In the far-IR (8–12 μm), the emitted energy dominates the target signature, with the appearance of targets dramatically changing with varying weather conditions and solar loading. Three examples were selected by the group; fixed wing or missile, helicopter of UAV, stationary or moving ground vehicle.

Fixed Wing or Missile

The skin of a Fighter Ground-Attack (FGA) aircraft or an incoming missile is aerodynamically heated to a temperature (kelvin) of T_s according to the equation:

$$T_s = \left(1 + \frac{\gamma - 1}{2}\beta M^2\right) T_a \qquad (1)$$

where T_a denotes ambient temperature; γ, the ratio of specific heats of air (≈ 1.4); M, the Mach number (based on velocity of sound, $V = 20.07\sqrt{T_a}$; and β, a recovery factor (≈ 0.82). The able shows skin temperature of two generic targets. The apparent temperature seen by the sensor will be less than the skin temperature due to emissivities of the materials and paints that are less than one.

Table 1: Speed and Temperature

	Speed (m/s)	(Mach)	T_s	$\lambda_{\max}$
Subsonic	300	0.88	$1.13T_a = 52°$C	8.9μm
Supersonic	1000	2.42	$2.42T_a = 424°$C	4.2μm

Attack Helicopter/UAV

The attack helicopter is one of the most complex targets in the infrared. It will have a typical friction heating of the skin of 2 to 3 degrees; engine exhaust of up to 500°C causes hot spots; the tips of the main rotors are moving near Mach 0.6 and hence are $30 - -40$°C above ambient, and changes in aspect angle can cause portions of the airframe to occlude hot spots. The signature, like that of the FGA is dominated by hot spots with weather conditions being a secondary impact.

Ground Targets

Ground targets are classified as Active (having been driven within the last 30 minutes; or passive. For active targets, hot spots dominate the IR signature with secondary effects based on ventilation and air temperature. The soil types and moisture levels also affect the temperature of tracks and wheels. High solar loading tends to raise the temperature of body parts and reduce the prominence of hot spots. Passive ground targets tend to be completely dominated by weather conditions *i.e.*, solar heating, precipitation, wind speed, cloud cover, etc.

Selecting Weather Vectors

We use the term 'weather vector' to describe a set of descriptive weather variables that describes the state of the atmosphere and subsequently its effect on sensor performance. The weather vector, when selected from an actual observation, represents an correlated state of the atmosphere. This is important, since average or extreme values of one variable may not occur at the same time as the average or extreme values of a second variable.

The values in the weather vector are: Visibility, Relative Humidity, Temperature, Pressure, Dew Point Temperature, Low Cloud Amount, Wind Speed, Wind Direction, and Precipitation. For each of these variables we produce a frequency of occurrence histogram and a cumulative probability chart.

Table 2: Some Weather Vectors

Vis	P	T	RH	Wind		Dew Point	Abs Hum
(km)	(mb)	(°C)	(%)	(dir)	Speed	(°C)	g/m^3
32	878	6	100	0	0	6	7.2
97	871	31	37	0	0	14	12.1

Process for Selecting Weather

The process starts with validating the data set, and analyzing the frequency of occurrence for each variable, as shown in figure 1. At this stage we also look for signs of 'unusual' distributions that might alert us to re-evaluate the process or suitability of the data-set for our analysis.

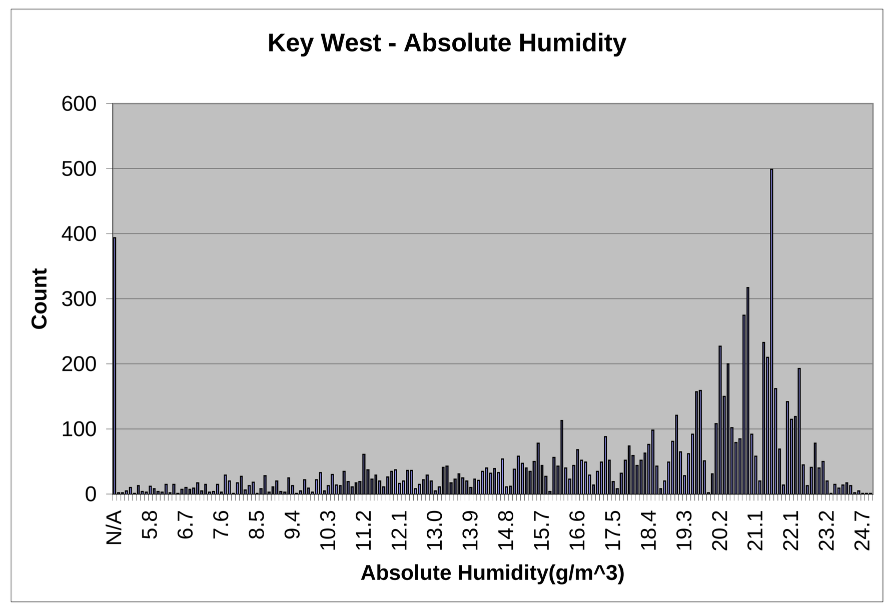

Fig 1: Histogram

In addition, we prepare a cummulative probability distribution to make it easier to select the 10 and 90 per cent values of the variable. We will want a table of the minimum (0%), 10% cumulative, mean, most probable, 90% cumulative, and maximum (100%) values.

After we performed the single variable analysis for all of the variables we prepare co-occurrance plots for all of the pairs of variables. One example is shown in figure 3 showing a cluster of data. At this stage we will be on the lookout for outlying data points; points that may not be outliers in the single variable analysis. We will examine the plots, paying particular attention to the perimeter of the clusters, looking for likely 'extreme' data. We are not looking for the absolute maxima or minima, especially as a design goal (engineering to meet the last several per cent of a broad distribution can be very expensive).

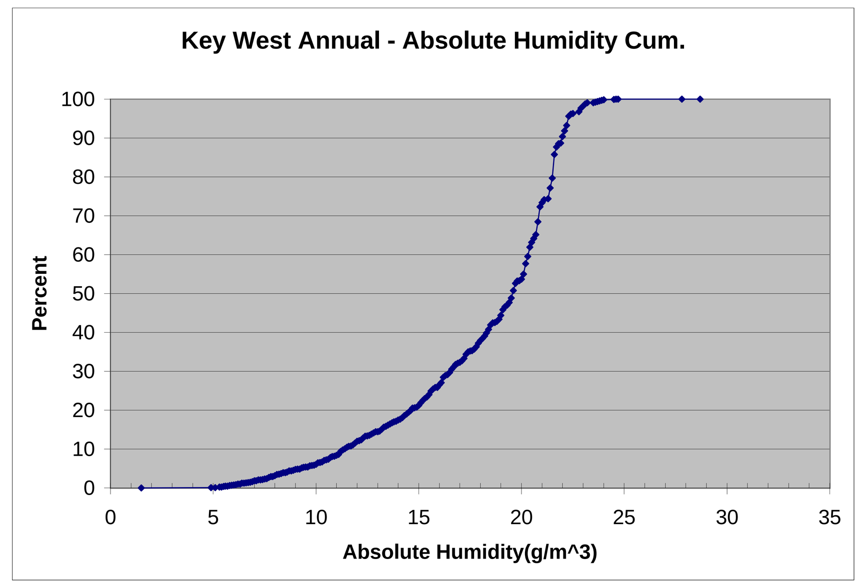

Fig 2: Cummulative Distribution

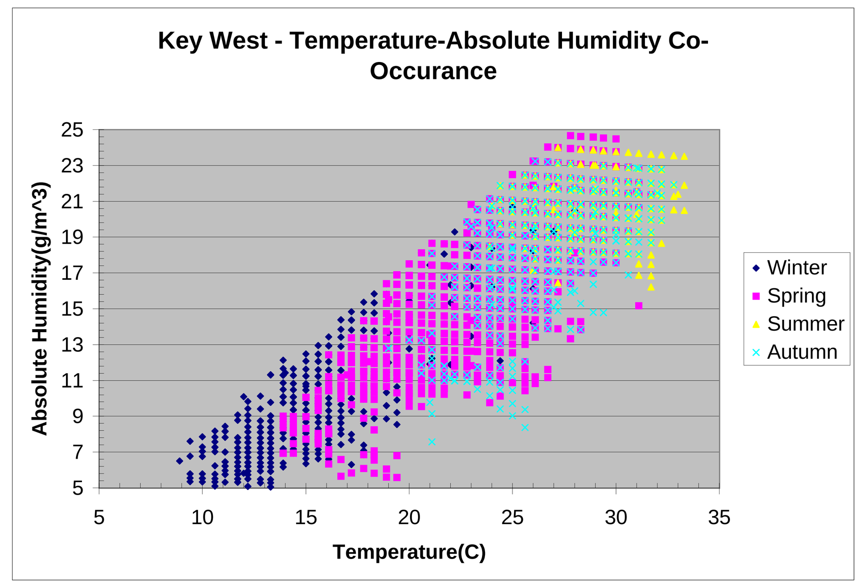

Fig 3: Co-Occurrance

After selecting a point near the edge of the cluster we identify the observation(s) to which it corresponds. We then review where each of the remaining variables for its position on the probability distribution. We want to select from the observations where as few of the other variables are near extremes.

The three most significant weather parameters influencing sensor performance are air temperature, absolute humidity, and visibility. If we select from the 10% and 90% points of the distributions we will have 8 vectors representing the extreme weather conditions; then we will add a final vector representing the average conditions. With limited resources for performing multiple performance analyses we will want to focus on the case of low visibility, high humidity, and high temperature as an example of difficult operational conditions. For the complete analysis we will want to repeat the weather vector selection process for each season, and perhaps also for day, night and cross-over times of day. Note that in figure 3 the weather observations during the different seasons form overlapping, but easily distinguished clusters.

Performance Modeling

One of the most variable and important processes that effects sensor performance is the propagation loss of the target's inherent signature through the intervening atmosphere. This loss is the product of loss from molecular absorption, absorption and scattering and by natural and battlefield aerosols. The total transmission can be calculated as the product of the transmission through each of the natural aerosols and battlefield aerosols and the transmission through the molecular gasses of the atmosphere.

The group used the Air Force's MODTRAN model for calculating the molecular extinction; and the Army EOSAEL models XSCALE for natural aerosol extinction and the COMBIC model for the battlefield smoke extinction. The calculations were done for the visible (0.4–0.7 μm); near-IR (0.7–01 μm); near-IR (1–2 μm); mid-IR (3–5 μm); and far-IR (8–12 μm); bands.

The sensor-to-target geometry used was to have one end of the path at 2 meters above ground, the other end of the path at 2, 50, 100, 200, or 500 meters above ground. For each of these five cases we form slant paths with a range of 50, 100, 200, 500, 1000, 2000, 5000, 10000, 20000, and 50000 meters. Not all of these cases are possible, there are, of course, no 50 meter paths between 2 meters above ground and 100 or more meters above ground. In addition, the reported cloud amounts and visibility are suitable for use by the illumination portions of various target signature models, for properly calculations the solar or lunar illumination. The weather dependent transmission losses along these paths were combined with the target thermal models and sensor performance curves to derive detection and lock-on range for each of the results.

Conclusions

The process of evaluating the effects of weather on sensor performance should be done using weather data where the variables are cross-correlated as they are in reality. This can be accomplished by using the actual weather observations, selected from a year or more of observations. By using two-variable correlation plots, we can select observations near the extremes and retrieve the data record. By using this carefully selected data record as our weather vector in the analysis we can guaranty a properly correlated set of data for performing the sensor analysis.

About Task Group 23

Task Group 23 was organized in 1999 and first met in the Spring of 2000 at the NATO RTA in Paris. The group has met approximately twice a year and has finished it's work this spring. The additional meetings were held at British Aerospace, Sowerby Research Center, Bristol, United Kingdom; RDDC Valcartier, Canada; Army Research Laboratory, Adelphi, USA; FGAN-FOM, Ettlingen, Germany. We identified key new scenarios where the assessment of EO sensor performance will be required but is currently not available. Generic scenarios were jointly selected by the Task Group and include both a traditional NATO area and newer operational areas. Specific locations exhibiting these conditions were identified and weather data produced. A statistical characterization of the data was undertaken which provided baseline information for the variability of weather conditions in which sensors must operate.